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**FLIGHT OPERATING PROBLEMS AND
AERODYNAMIC AND PERFORMANCE
CHARACTERISTICS OF A FIXED WING, TILT
- DUCT, VTOL RESEARCH AIRCRAFT**

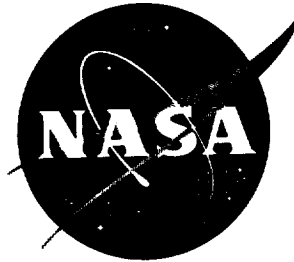
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TECHNICAL NOTE

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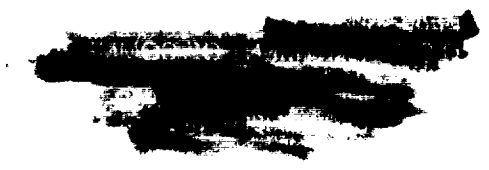
By Henry L. Kelley and Robert A. Champine

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Langley Station, Hampton, Va.

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SUMMARY

This report presents the results of a flight investigation conducted at the Langley Research Center and includes some of the operating problems and related aerodynamic characteristics of a tilt-duct, fixed-wing, vertical-take-off-and-landing (VTOL) configuration.

Buffet-boundary (stall onset) angles of attack, which limited the operational capabilities of this tilt-duct test aircraft, were found to vary considerably over the transition speed range, as well as with power setting. Generally, the stall-free operational range of angles of attack was decreased when operating at reduced power.

Simulated ground-controlled landing approaches were investigated at various duct angles and glide-path angles by the use of three methods. The results of one method studied (that of increasing the duct angle by 10° upon intercepting the glide slope) indicated that satisfactory characteristics (handling and flying qualities and pilot work load) were possible with a fixed-wing, tilt-duct fan configuration. When this approach method is used, the duct-angle setting on the glide path was 60° and the airspeed was between 50 knots and 60 knots, depending on the glide angle used.

Also presented is an extension of flight-test results in an earlier report which includes stability, control, and performance characteristics recorded over a speed range from 15 to 122 knots which includes duct angles from 80° to 0° .

INTRODUCTION

Research has been conducted by the National Aeronautics and Space Administration on vertical-take-off-and-landing (VTOL) model configurations and flying vehicles to obtain a background of information for designers of future VTOL aircraft. Full-scale flight-test programs at Langley Research Center have been conducted on two configurations - the tilt wing and the tilt duct. Earlier flight-test results on the tilt-wing configuration are presented in references 1

and 2. References 3 to 10 present some additional flight and wind-tunnel results on tilting ducted-fan VTOL configurations. The results of this investigation were obtained by using the tilt-duct research aircraft.

One important operational problem for a fixed-wing VTOL aircraft is the landing approach where flow angles induced by the lifting elements cause flow separation (stall) over parts of the wing at low angles of attack relative to the free airstream. Even at relatively low dynamic pressures, satisfactory handling and flying qualities are possible only when the lifting surfaces are unstalled. Consequently, wing angles of attack relative to the free airstream must be maintained low enough so that stall or unsteady flow conditions over the wing are not encountered during the corrective maneuvers required to maintain an approximately constant glide slope. With the fixed-wing, tilt-duct configuration it is possible that suitably low angles of attack can be maintained at a given airspeed and glide slope by using different combinations of duct-angle setting, attitude angle, and power setting.

This paper presents the results of efforts to use various combinations of aircraft attitude, airspeed, and angle of attack during simulated ground-controlled landing approaches. Some effects of flow separation over the wing on the operationally useful combinations of these parameters are discussed.

An extension of the basic stability and control characteristics reported in reference 4 is also included in this report. Static stability at the lower airspeeds, maneuver-stability, roll-control, and power-required characteristics are presented.

Pilot opinion included in this report represents the combined opinions of three experienced NASA pilots.

SYMBOLS

g	gravitational acceleration units, 32.2 ft/sec^2
i	horizontal-tail incidence angle, deg
P	engine shaft horsepower, hp
V	indicated airspeed, knots
α_f	fuselage angle of attack with respect to free stream, deg
α_w	wing angle of attack, $\alpha_f + 2.5^\circ$, deg
β	angle of sideslip, deg
δ_d	duct angle with respect to wing chord line, deg

APPARATUS

Aircraft

Figures 1 and 2, respectively, show a three-view sketch and an in-flight photograph of the test aircraft. This vertical-take-off-and-landing flying test bed is similar in configuration to a conventional airplane, with the exception that a tilting ducted-fan assembly is mounted at the tip of each wing. The thrust axis of the ducted fan can be rotated from a position perpendicular to the wing-chord plane for hovering flight to a position essentially parallel to the wing chord for high-speed flight. Table I presents the physical characteristics of the tilt-duct aircraft.

Instrumentation

Airspeed, rate of descent, fuselage angle of attack, angle of sideslip, duct angle relative to the fuselage, horizontal-stabilizer angle, engine-output shaft speed, and engine-gearbox oil pressure (which provides torque output reference) were recorded by two motion-picture cameras photographing the pilot's instrument panel. Recorded on a 14-channel oscillograph were the aircraft angular velocities about the roll, pitch, and yaw axes, as well as lateral-, longitudinal-, and directional-control positions. Also recorded on the oscillograph was the normal acceleration of the aircraft. Motion-picture data and oscillograph data were synchronized.

Additional instrumentation, used during the steep-approach investigation, included a directional gyro mounted in the aircraft and a gunsight camera located on the ground. The gunsight camera was set up in such a way that the ground-control operator could relay glide-path corrections to the pilot and, at the same time, actuate the gun camera to record flight-path deviation.

Control Systems

The test aircraft incorporates two control systems: one for hovering and low-speed flight, and one for conventional or cruise flight. The ailerons, elevator, and rudder were actuated in normal fashion for the cruise flight region. In the hovering flight region, control moments were provided about the roll axis by 14 guide vanes arranged radially in the inlet of each duct. Pitch and yaw control moments were provided by articulated pitch and yaw control vanes located in the engine exhaust gases. The inlet guide vanes were phased in and out in the transition region. The pitch and yaw control vanes were not phased out in the transition region. These control systems are described in more detail in reference 3. Table II presents the number, dimensions, deflections, and so forth, of the various components of these control systems. Automatic stabilization equipment was not included in the control system.

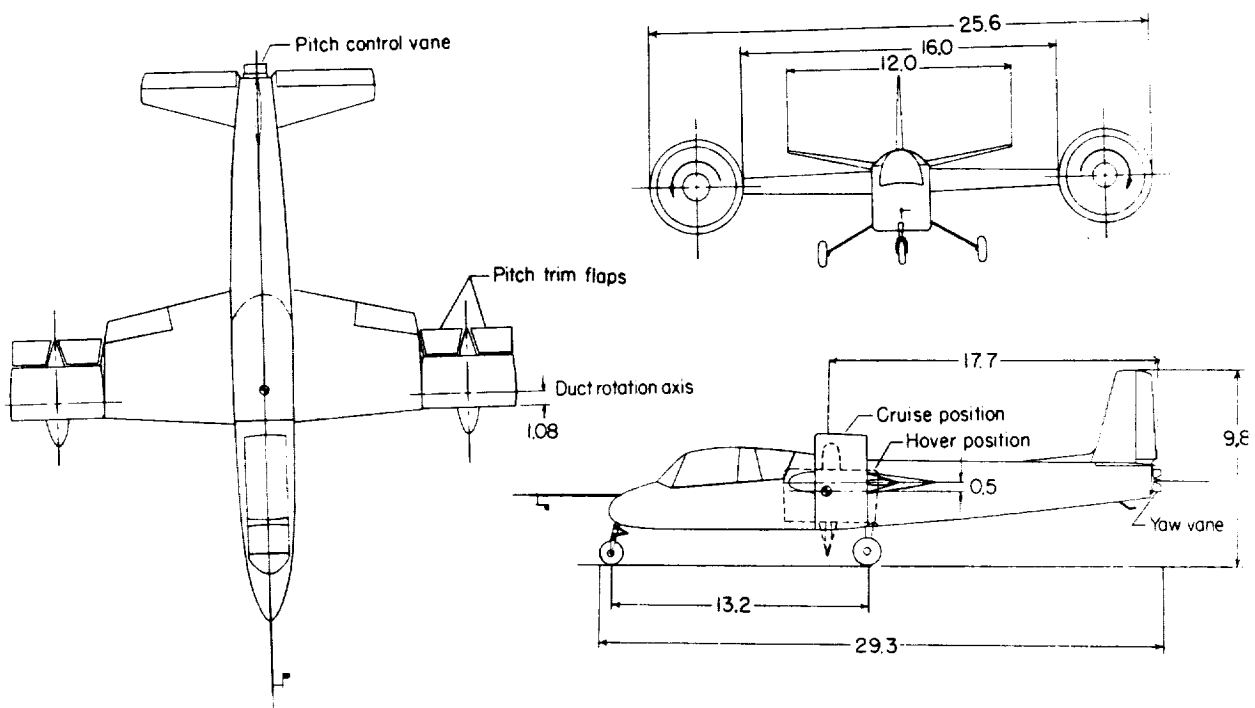
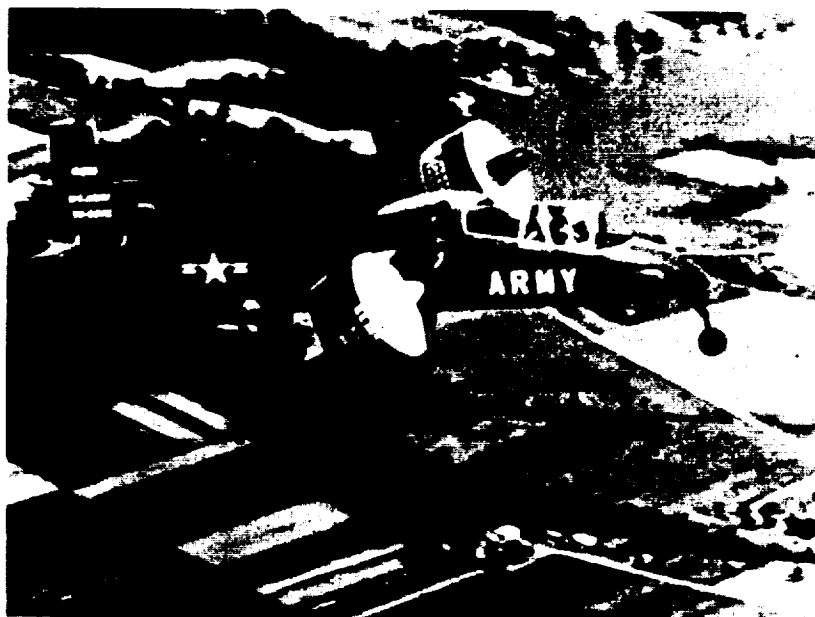


Figure 1.- Sketch of tilt-duct VTOL aircraft. (All dimensions are in feet.)



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Figure 2.- Aerial view of tilt-duct VTOL research aircraft.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRCRAFT

ducted propellers:		
Diameter, ft		4
Number of blades (each fan)		8
Rotational speed (maximum), rpm		4,800
ducts:		
Inside diameter, ft		4
Chord, ft		2.75
Rotation, deg		92
centerbody:		
Length, ft		5.78
Diameter (maximum), ft		1.33
pitch trim flaps:		
Span, ft		4.5
Chord, ft		1.29
Deflection (maximum), deg		23
straightening vanes (stators):		
Number of blades (each duct)		9
Length, ft		1.33
Chord, ft		0.5
wing:		
Span (excluding ducts), ft		16
Overall span (including ducts), ft		25.6
Mean aerodynamic chord, ft		6.08
Airfoil section	Modified NACA 2418	
Taper ratio		0.747
Sweep, deg		0
Dihedral, deg		0
Area, sq ft		96
Area of each aileron, sq ft		3.0
Incidence, deg		2.5
vertical tail:		
Height, ft		5.18
Average chord, ft		2.75
Airfoil section	Modified NACA 0012	
Area, sq ft		1.39
horizontal tail:		
Area, sq ft		28.5
Airfoil section	Modified NACA 0012	
Span (projected), ft		12.0
Dihedral, deg		10
fuselage length, ft		29.3
overall length (including boom), ft		31.2
engine	Lycoming YT53-L-1 and T53-L-1A	
weight as flown, lb		3,200
moments of inertia (approximate):		
Pitch, slug-ft ²		1,500
Roll, slug-ft ²		2,900
Yaw, slug-ft ²		3,100
center of gravity:		
Forward, percent M.A.C.		25
Rearward, percent M.A.C.		32

TABLE II.- DIMENSIONS AND CHARACTERISTICS OF CONTROL SURFACES

Control	Moment source	Number	Maximum deflection	Chord, in.	Span, in.	Area, sq ft	Miscellaneous
Roll	Ailerons	2	14.7° up 13.5° down	12	37	3.0	Lateral stick travel = ±7.25 in. (at top of stick)
	Inlet guide vanes	14 each duct	17° total travel	3	18	0.375 each	
Pitch	Elevator	1	26.5° up 24.5° down	M.A.C. = 9	62.7	3.92	Longitudinal stick travel = ±6 in. (at center of grip)
	Pitch-control vane	1	{ 1st segment, 6.7° 2nd segment, 37.5° 3rd segment, 67.7°	{ 1.8 5.2 3.0 } 10	19.5	1.36	Articulated
	Pitch trim flap	2	23°	15.5	54	-----	
Yaw	Rudder	1	26° left 26° right	M.A.C. = 8	57	3.17	Pedal travel = ±3.5 in.
	Yaw-control vane	1	{ 1st segment, 3° 2nd segment, 18° 3rd segment, 37°	{ 1.87 5.2 3.05 } 10	19.5	1.36	Articulated

RESULTS AND DISCUSSION

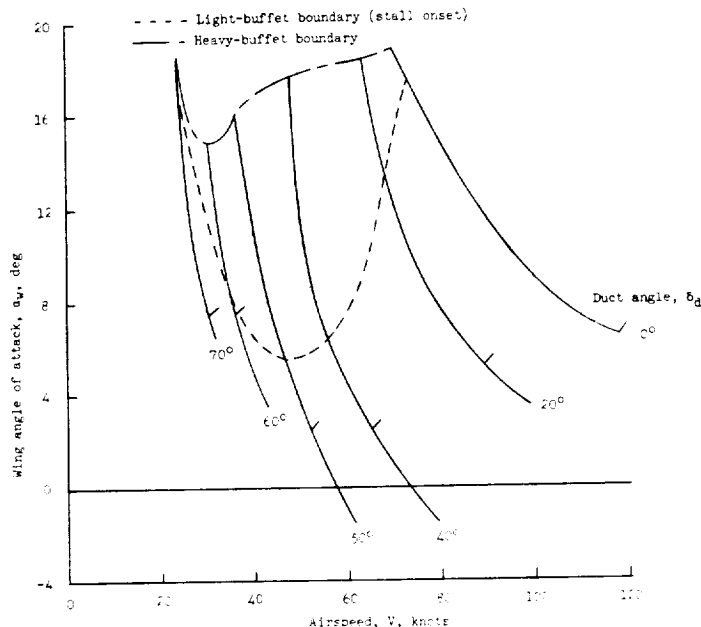
Operating Problems and Related Aerodynamics

Stall boundaries.- Flight-test results on the tilt-duct aircraft during investigation of the stall-onset and heavy-buffet boundaries were obtained throughout the transition speed range at two power settings at each duct angle. The investigations were made at a power setting required for level flight at the trim condition for a given duct angle and, also, at a reduced power setting (power required for a rate of descent of 500 feet per minute). At each duct angle, the test runs were begun in level flight and at a low wing angle of attack. With the power setting held constant, the range of angle of attack was slowly traversed (a rate of change in airspeed of less than 1 knot per second). The results of flow separation over the wing tips and ailerons were first felt by the pilot through the control stick and runs were continued until heavy buffeting of the entire airframe was felt. The lowest angle of attack obtained was limited by the

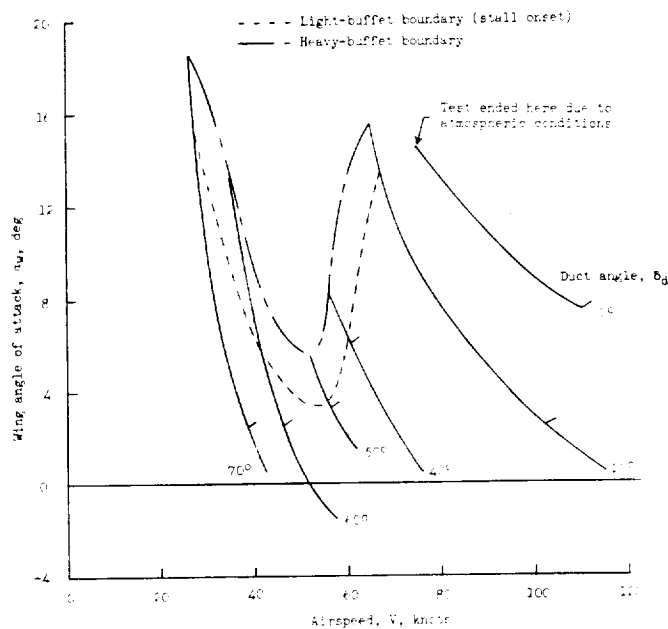
pilot due to the steep dive angles and/or high descent rates encountered during the test runs.

Curves which define areas of smooth flight and areas of increasingly rough flight throughout the transition speed range are presented in terms of angle of attack, airspeed, and duct angle in figure 3. Figure 3(a) presents the light-buffet boundary (stall onset) and the heavy-buffet boundary over a speed range from 24 to approximately 120 knots (duct angles between 70° and 0°) at power initially set for trim level flight at angles of attack and airspeeds indicated by the flags on the curves for each duct angle. Figure 3(b) presents the same information at a reduced-power setting (power for a rate of descent of 500 feet per minute at initial trim condition for each duct angle).

The light-buffet boundary (stall onset) represents the wing angle of attack over the transition speed range at which the aircraft experienced light buffeting, lateral stick "snatching," and noncontrol-induced rolling motions. The heavy-buffet boundary represents the combination of angle of attack and speed at which the aircraft began to shake violently and lateral stick snatching and noncontrol-induced rolling motions became more pronounced; consequently, the pilot believed he must push the nose of the aircraft down to obtain a lower angle of attack and regain proper control. All these effects, the magnitude of which increased when going from the lower boundary to the higher boundary, were caused by flow separation on the



(a) Power for level flight at initial trim condition.



(b) Power for rate of descent of 500 feet per minute at initial trim condition.

Figure 3.- Stall-onset and heavy-buffet boundaries over transition range. (Flags on duct-angle curves indicate initial trim condition.)

outboard portion of the wings and ailerons adjacent to the ducted-fan units. The problem of flow separation is discussed in more detail in reference 4. Furthermore, it should be noted from the light-buffet boundary (stall onset) that the conditions for onset of these effects were found to vary considerably over the transition speed range. At the low airspeeds of the investigation (24 to 35 knots), which include duct angles between 70° and 60° , there was a comparatively wide angle-of-attack range available for maneuvering flight. At these high duct angles, flow separation was probably present at the outboard sections of the wing; however, the low-energy slipstream did not produce sufficient buffet forces to affect the pilots' opinions. In the airspeed range between 35 and 60 knots (duct angles between 35° and 60°) the initial buffet boundary dropped considerably to lower angles of attack; hence, the angle-of-attack range available for maneuvering flight (angle-of-attack range at which no buffet or stick snatching was noted) was small. As the airspeed range was increased to 60 to 120 knots (duct-angle range between 35° and 0°), the angle of attack available for maneuvering flight became wider again.

Figure 4 is a comparison of the initial stall-onset boundaries for the power for level flight and the power for cases when the rate of descent is 500 feet per minute as a function of duct angle throughout the transition speed range. It may be noted from figure 4 that at duct angles above 40° the angle-of-attack range available for smooth flight is from 0° to 3° less when operating at the reduced-power setting. At duct angles below 40° the effect of the reduced-power condition on the range of angle of attack available for smooth flight is shown to have no effect on the initial stall-onset boundary.

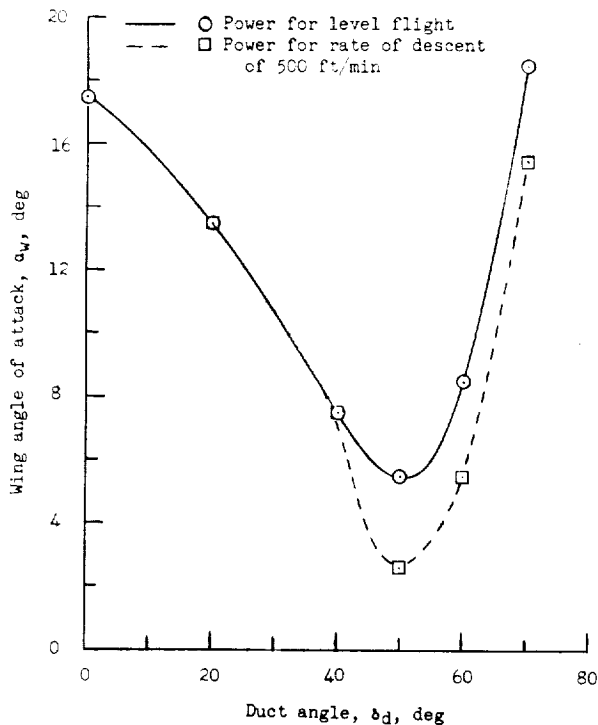


Figure 4.- Effect of power on stall-onset boundaries.

Simulated ground-controlled landing approaches.- In order that the operational limitations imposed by the stall boundaries be studied, simulated ground-controlled landing approaches were made at duct angles of 20° , 40° , 50° , and 60° for an airspeed range from 100 to 35 knots and at glide-slope angles between 3° and 13° . The pilot had visual contact with the ground at all times during the approaches, but he made glide-path corrections from instructions received by radio from a ground controller. Three landing-approach methods were studied. The first method was to hold a constant wing angle of attack well below the stall boundary throughout the approach. This was accomplished by the pilot's increasing the nose-down attitude of the aircraft and allowing the airspeed to increase as power was reduced for descent along the glide slope. A second method was used whereby airspeed was held constant and the wing

angle of attack was allowed to increase with power reduction. The third method involved increasing the duct angle approximately 10° above the initial level-flight setting upon intercepting the glide slope, thus carrying more load on the ducted fans and permitting a lower wing angle of attack, without a need for the undesirable increase in airspeed on the glide slope experienced with the first method. The particular duct angles and glide-slope angles used during the approaches are shown in table III along with the attempted methods employed.

TABLE III.- COMBINATIONS OF DUCT ANGLES, GLIDE-SLOPE ANGLES, AND METHODS USED DURING SIMULATED GROUND-CONTROLLED LANDING APPROACHES

Glide-path duct angle, deg	Glide-slope angle, deg	Method used ^a
20	5.5	1
20	8.5	1
20	12	1
40	6	1 and 2
40	9	1 and 2
50	3	1
50	6	1
50	9	1
60	7	3
60	10	3
60	13	3

^aMethod 1: Hold constant angle of attack by allowing airspeed to increase with reduction in power.

Method 2: Hold constant airspeed allowing the angle of attack to increase with reduction in power.

Method 3: Maintain a low constant angle of attack and increase the duct angle by amount required to prevent airspeed increase upon entering the glide slope.

Flight trials of the first method, which involved an increase in airspeed of 10 to 15 knots after intercepting the glide slope together with steep nose-down attitudes, were reported by pilots to produce too steep a nose-down attitude; therefore, the first method was considered as an unsatisfactory approach method. As expected, high wing angles of attack encountered while investigating the second method produced unsatisfactory handling characteristics. For the range of duct angles tried, the third method appeared to provide considerable improvement to the steep nose-down attitude brought about by the speed increase inherent in the first method. The increase in duct angle upon intercepting the

glide slope resulted in the pilot's being able to hold a low angle of attack during the descent with no appreciable increase in speed. For one particular descent, where the duct angle was increased from 50° to 60° upon intercepting a glide-slope angle of 10° , no change was noted in airspeed (which remained at about 50 knots), and wing angle of attack was kept below 5° . Initial indications were that this method might offer the greatest potential for steep approaches with the fixed-wing type of VTOL aircraft; however, controllability and performance limitations, other than effects of stall boundaries, of the test aircraft at duct angles higher than 60° and airspeeds lower than about 45 knots did not permit further exploration of the steeper angles and lower speeds believed desirable for VTOL operation. Moreover, the hazard of an engine failure near the ground at higher duct angles with this particular aircraft precluded making steep descents at low altitudes, where actual landing flare and touchdown could be studied. Consequently, it was not possible to determine probable limits of pilot tolerance to the steep nose-down aircraft attitudes required by this method for steep, slow-speed approaches or to study problems involved with rotating the aircraft through the large attitude changes which would be required for a landing touchdown following the descent.

Stability, Control, and Performance Characteristics

Apparent speed stability.- Speed-stability results at constant duct angles were obtained at several conditions in the transition speed range, each at an initial power setting required for level flight. The results are presented in figure 5 as longitudinal stick position plotted against airspeed for a series of fixed duct angles between 0° and 70° . The slopes of the curves of the stick position plotted against speed indicate that the aircraft is statically stable over the speed range of the investigation. The aircraft generally seems to become more stable with speed as the initial trim airspeed decreases and as the duct-angle setting increases, with the exception of the case in which, for a 50° duct angle, the magnitude of stability decreased. Pilots indicated that the static longitudinal characteristics were satisfactory throughout the range of the investigation. It is possible, however, that at the lowest speeds the apparent speed stability might have been found to be excessive in rough air.

It should be noted from figure 5 that for a duct angle of 0° the slope of the curve at the high speeds appears to become unstable. This nose-down tendency is believed to be due to a power reduction caused by the governor on the engine, rather than to a more basic instability with airspeed; this governor reduces fuel flow to prevent engine overspeed at this condition. Also, it may be noted from comparison of the speed ranges covered for each duct angle in figure 5, that the speed range available (limited by aircraft attitude angles and/or aircraft buffeting) at a given duct angle gets smaller as the duct angle increases.

Maneuver stability.- With the test vehicle approximately in the airplane configuration (duct angles of 0° and 15°), maneuver-stability data were obtained by executing windup turns. At the higher duct angles (20° , 40° , 50° , and 60°), the maneuver-stability data were obtained by using the helicopter flight-test method. (See ref. 11.)

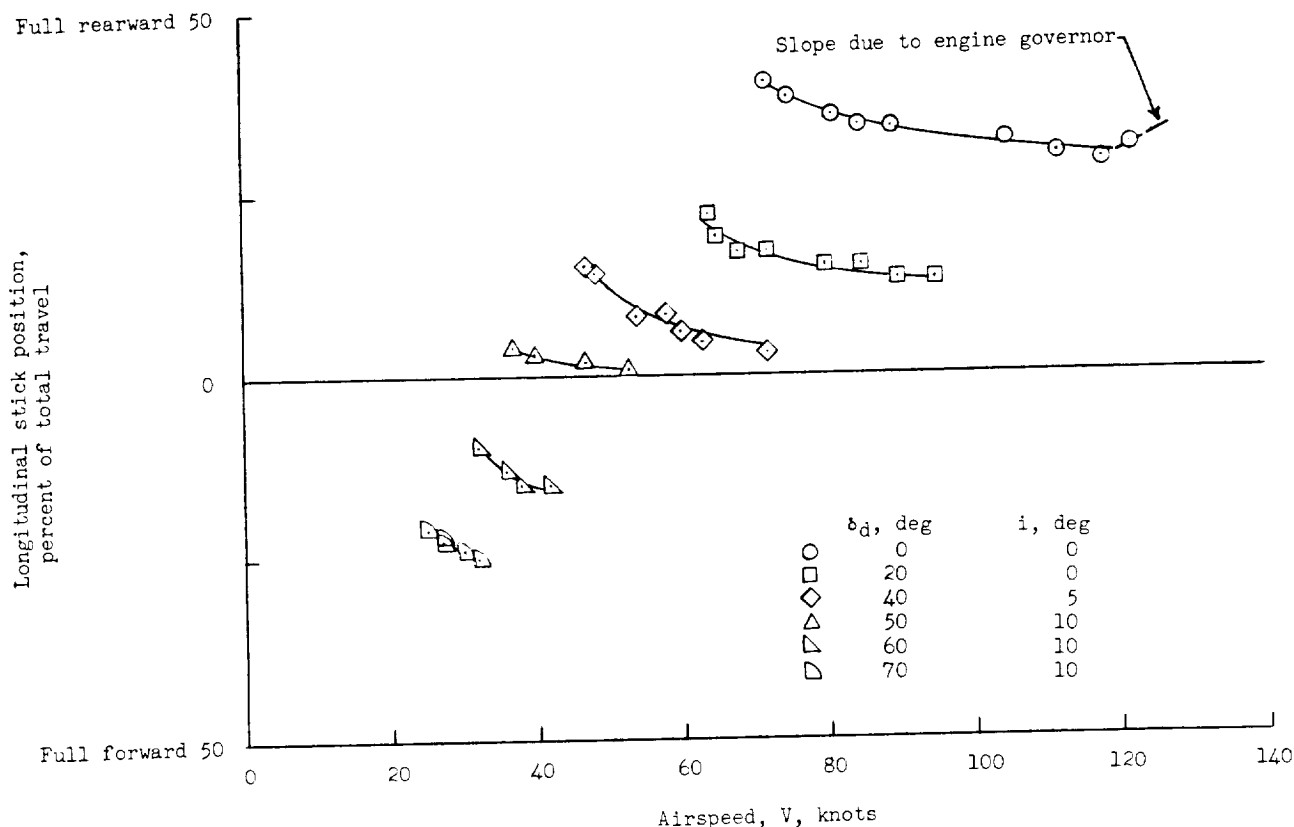


Figure 5.- Variation of trim longitudinal stick position with airspeed for constant power settings at various duct angles.

Results of maneuver-stability measurements are presented in figures 6, 7, and 8. Figures 6 and 7 show the longitudinal stick position plotted against normal acceleration for steady level flight at duct angles of 0° and 15° , respectively. The slopes of the curves indicate that the test aircraft should have satisfactory maneuver-stability characteristics. Figure 8 shows time histories of the results of longitudinal pull-and-hold maneuvers for the several duct angles starting from trim level flight. Normal acceleration, pitching angular velocity, and longitudinal stick position are plotted for each case to describe the maneuver. In general, the maneuver-stability characteristics were judged to be satisfactory over the high-speed flight conditions ($V > 60$ knots) covered in this investigation; however, the stability at the low airspeeds, as represented by the time histories in figures 8(c) and (d), diminished to a point that the aircraft was considered by pilots to have unsatisfactory maneuver-stability characteristics. The fact that the pilot was unwilling to hold the step stick deflection long enough (2 seconds) to get the necessary data to compare the results with the criteria of reference 11 is a further indication of unsatisfactory maneuver-stability characteristics at low airspeeds. It can also be noted that in spite of partial corrective action, figure 8(d) shows an approximately linear rather than concave-downward angular-velocity response for about 1 second.

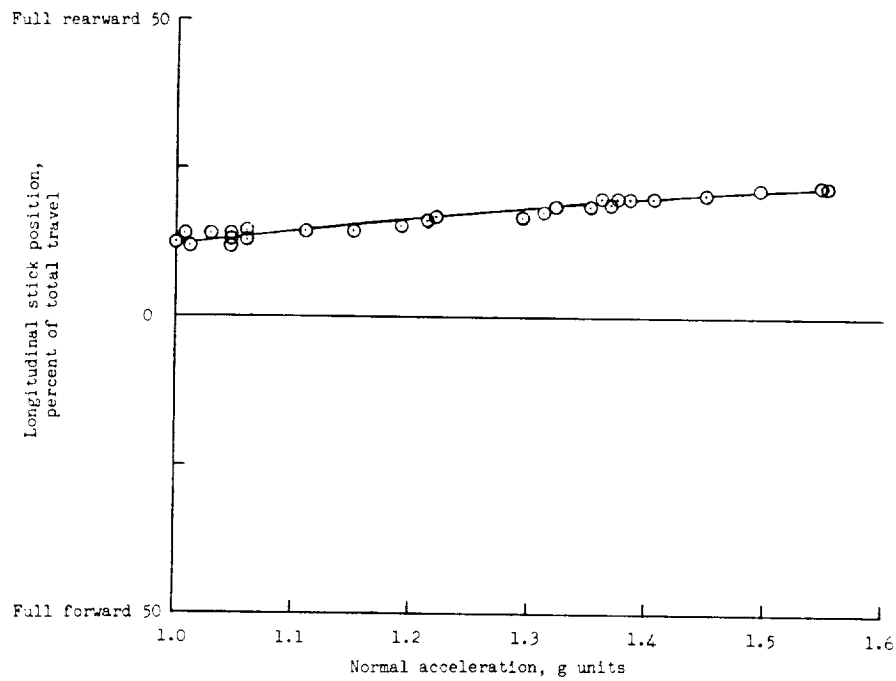


Figure 6.- Results of windup turn at $V = 114$ knots for $\delta_d = 0^\circ$.

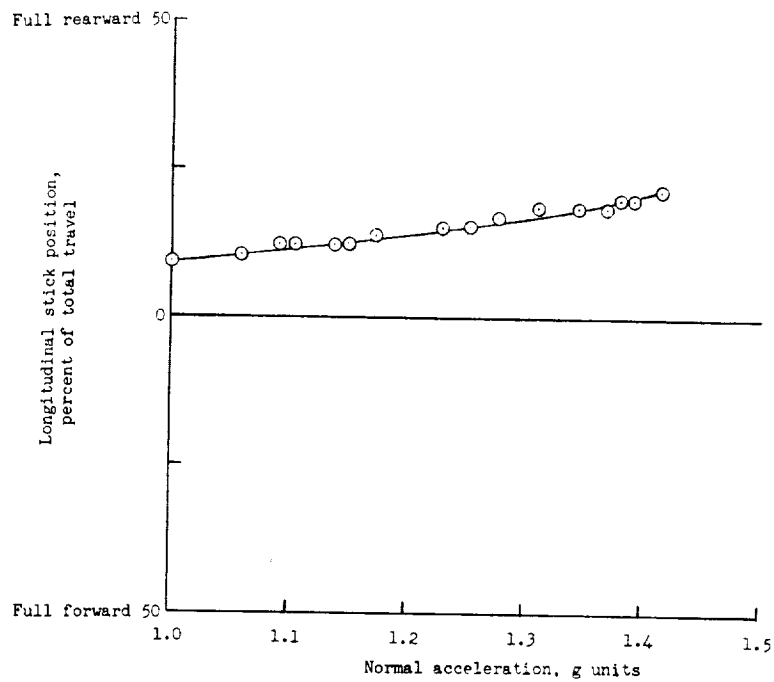
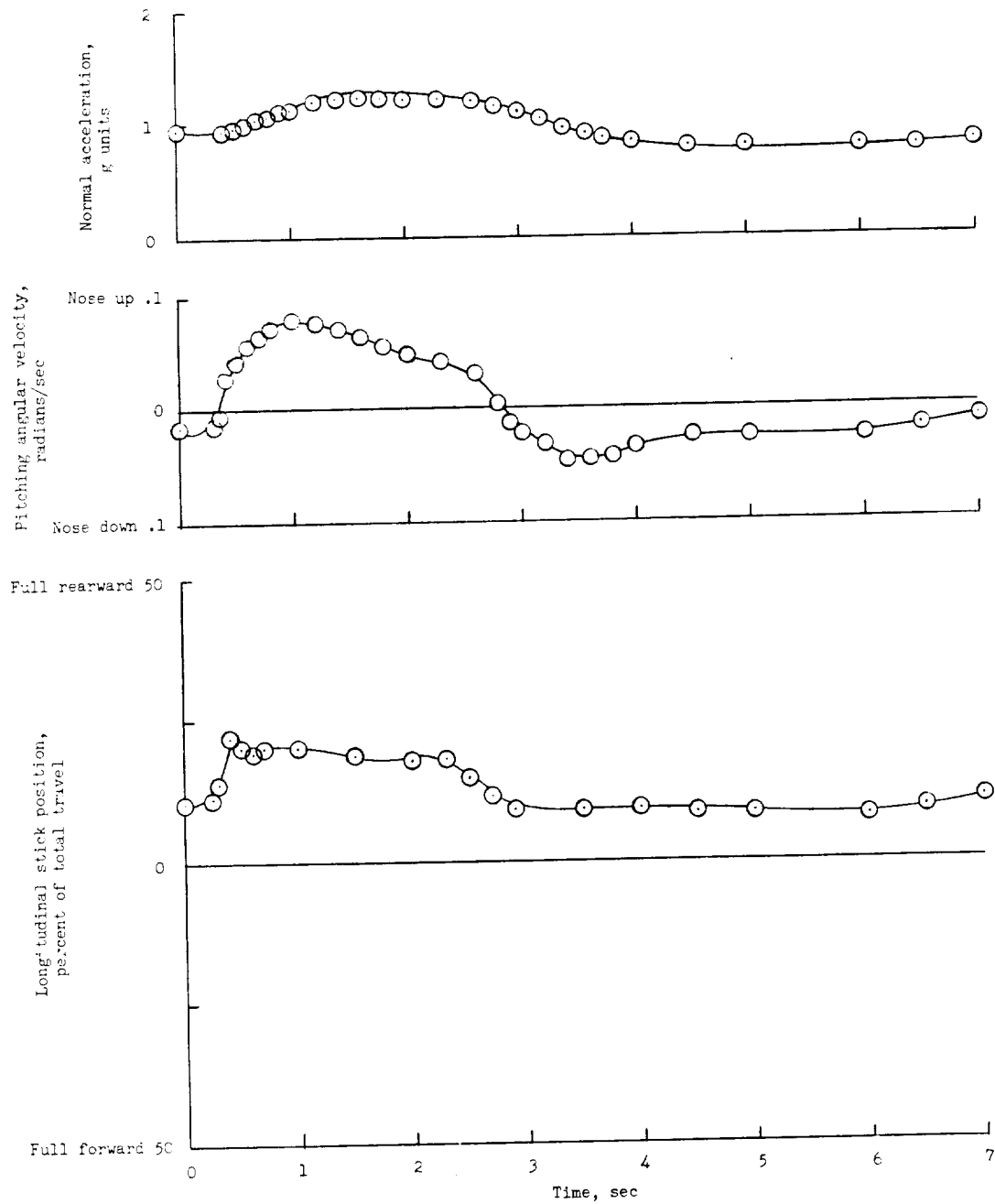
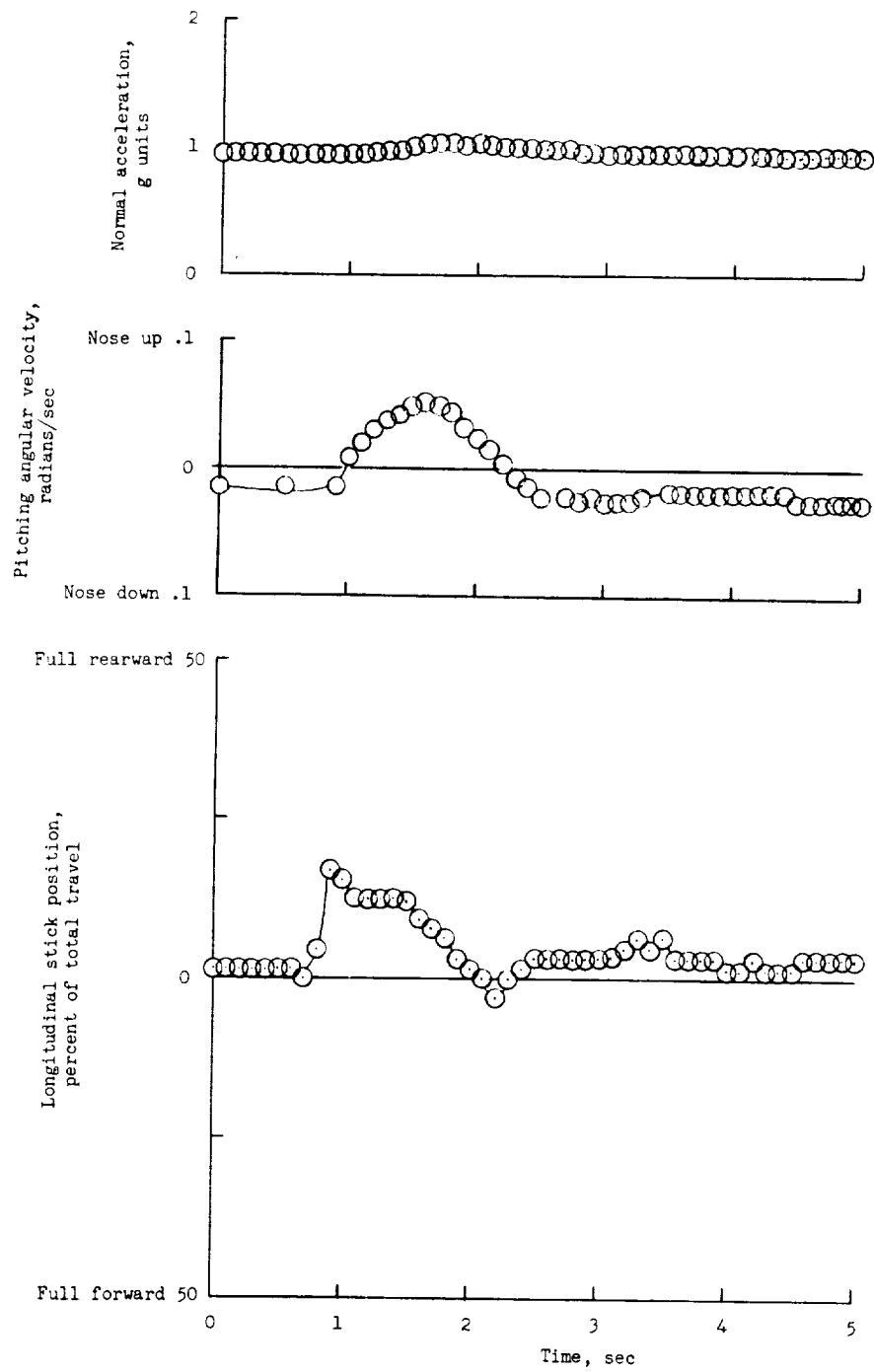


Figure 7.- Results of windup turn at $V = 87$ knots for $\delta_d = 15^\circ$.



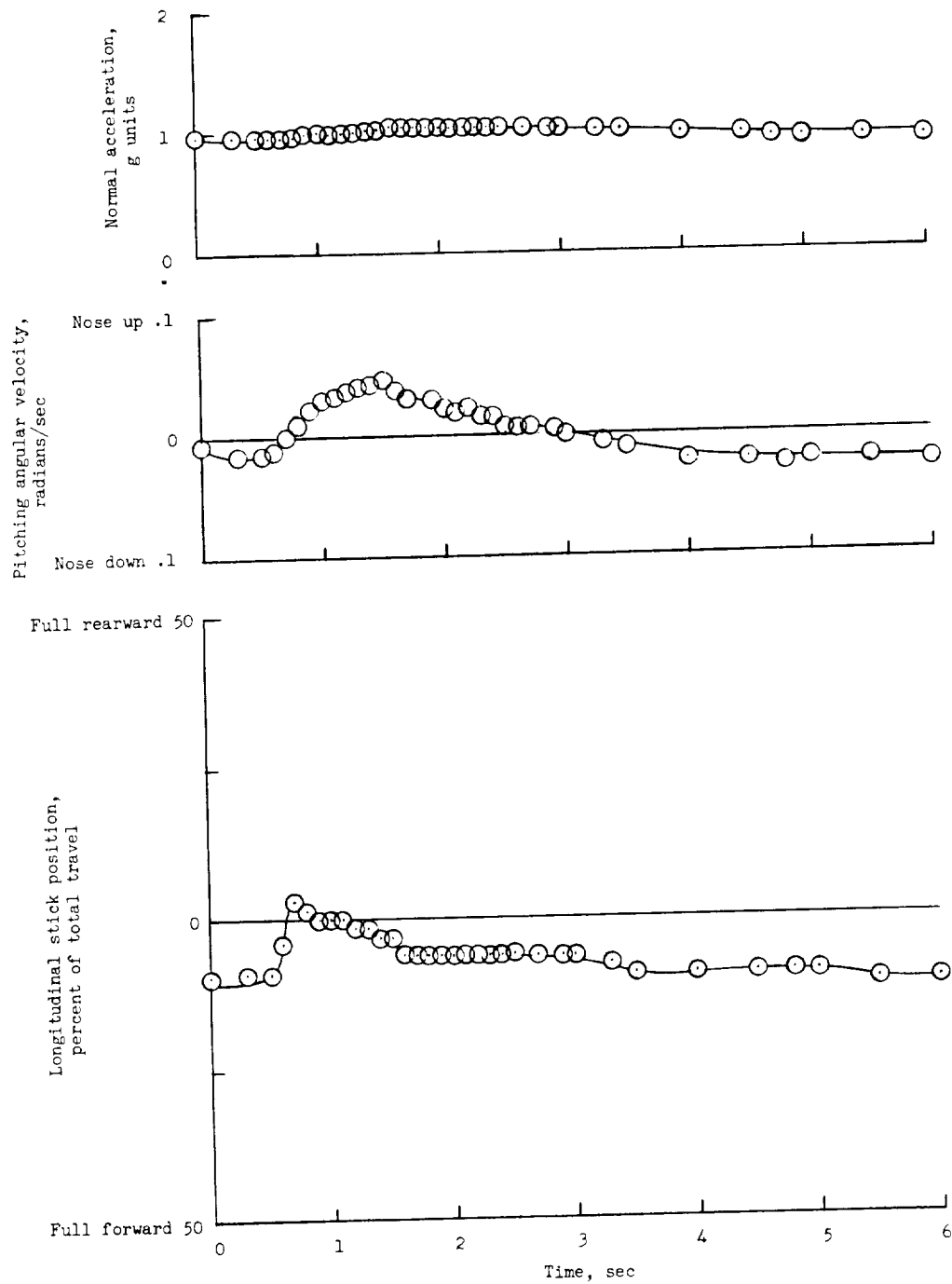
(a) $V = 77$ knots; $\delta_d = 20^\circ$.

Figure 8.- Time histories of longitudinal pull and holds showing the resulting normal acceleration and pitching angular velocity for four different flight conditions.



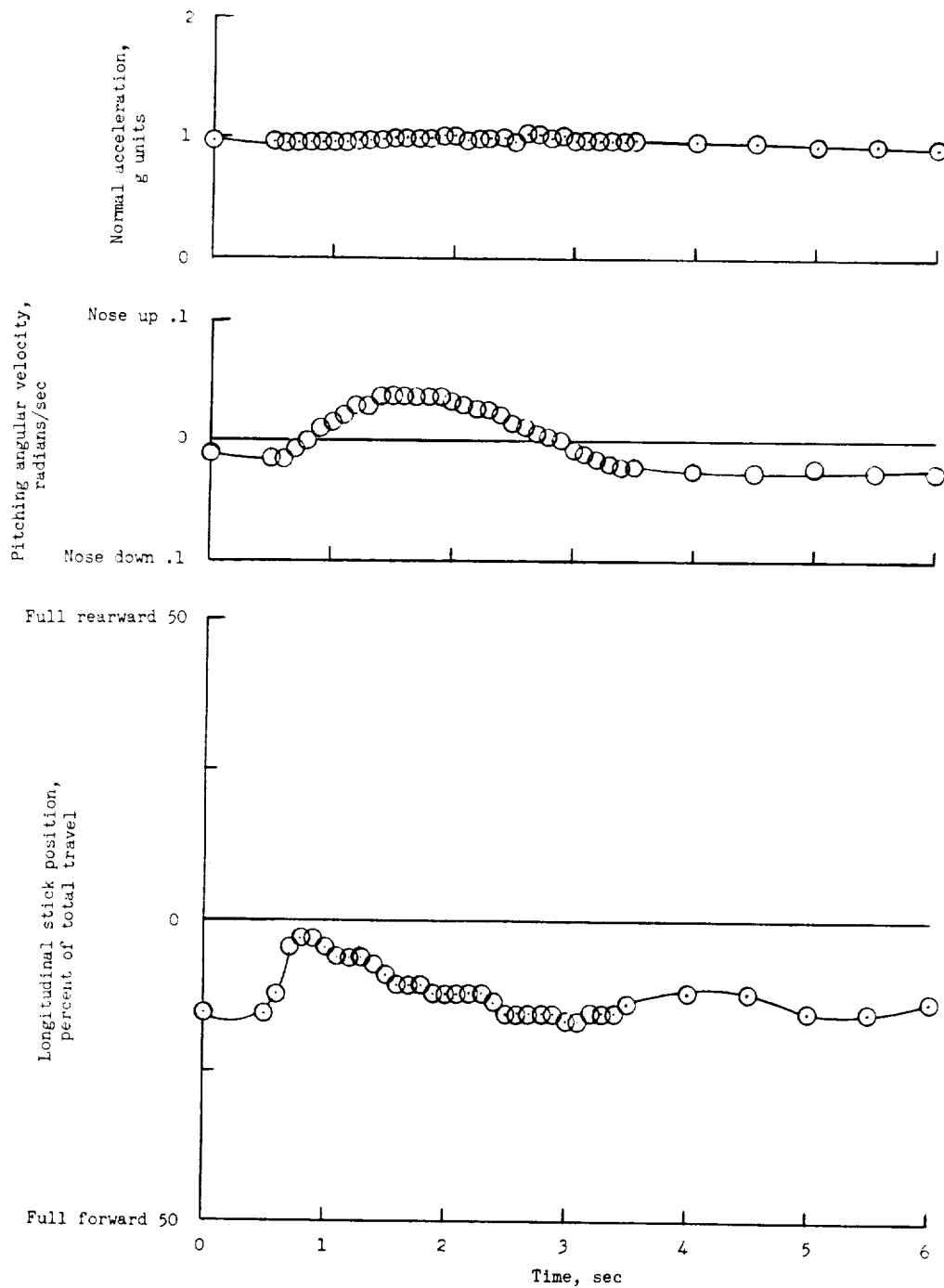
(b) $V \approx 58$ knots; $\delta_d = 40^\circ$.

Figure 8.- Continued.



(c) $V = 45$ knots; $\delta_d = 50^\circ$.

Figure 8.- Continued.



(d) $V = 33$ knots; $\delta_d = 60^\circ$.

Figure 8.- Concluded.

Normal acceleration response to longitudinal pull and holds at airspeeds below approximately 58 knots and at duct angles of 40° and above was practically zero, as can be seen from figures 8(b), (c), and (d). In order to achieve a normal acceleration response with the test aircraft at lower airspeeds, a power change was required.

Apparent effective dihedral.- The dihedral effect (variation of lateral stick position with sideslip angle) of the tilt-duct aircraft was measured at duct angles of 60° and 70° . Reference 4 presents the apparent dihedral effects for the tilt-duct aircraft at duct angles of 0° , 20° , 30° , 40° , and 50° starting from trim level flight. The results of the studies of dihedral effect for the cases when $\delta_d = 60^\circ$ and 70° are presented in figure 9 where the results are shown as lateral stick position plotted against angle of sideslip. In both cases,

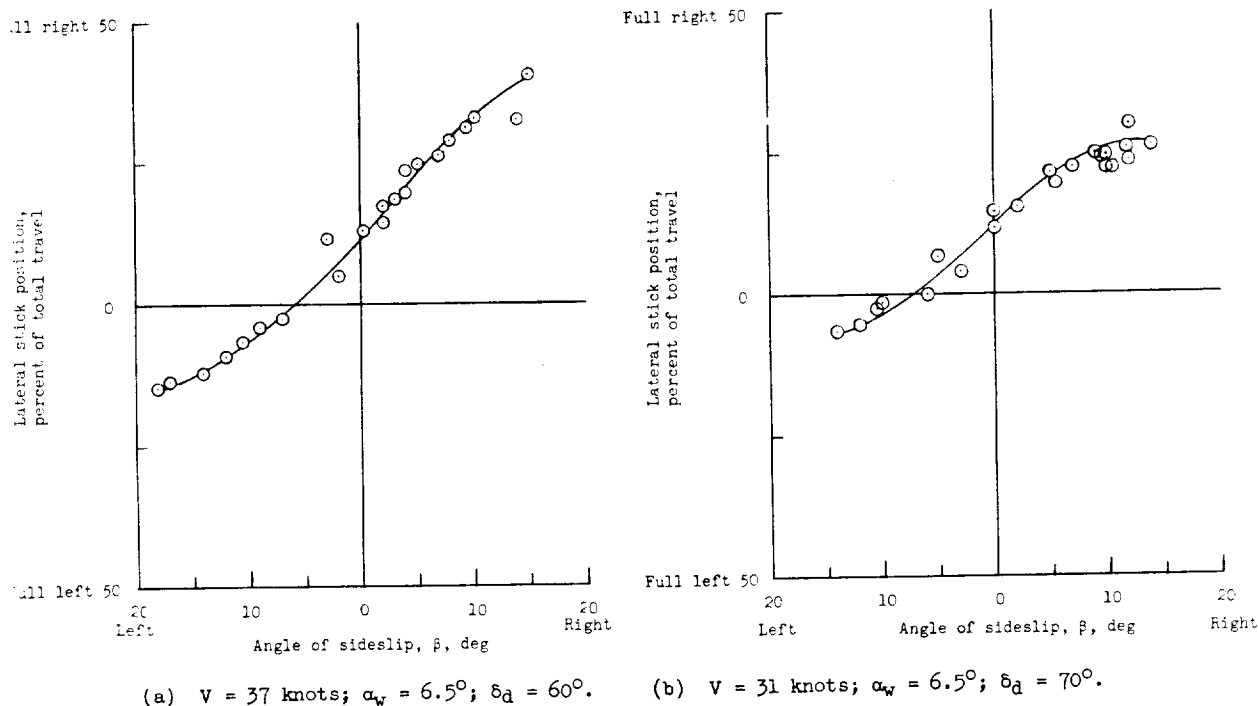


Figure 9.- Dihedral effects for level-flight configuration at two low-speed conditions.

satisfactory apparent effective dihedral is indicated. Figure 10 shows the effective dihedral for all the duct angles tested (0° to 70°) plotted against airspeed. These data indicate that the apparent static lateral stability (discussed in ref. 4) decreases with increasing speed (up to 50 knots) and then increases with increasing speed above 50 knots; in general, however, pilot comment indicates that apparent effective dihedral went from satisfactory at the high speeds of the transition speed range to unsatisfactory at the lower speeds of the transition speed range. The roll-control power was very weak and overall control in rough air was unsatisfactory.

Apparent directional stability.- The apparent static directional stability (variation of pedal position with angle of sideslip) has been investigated for duct angles of 60° and 70° as an extension of the apparent directional-stability

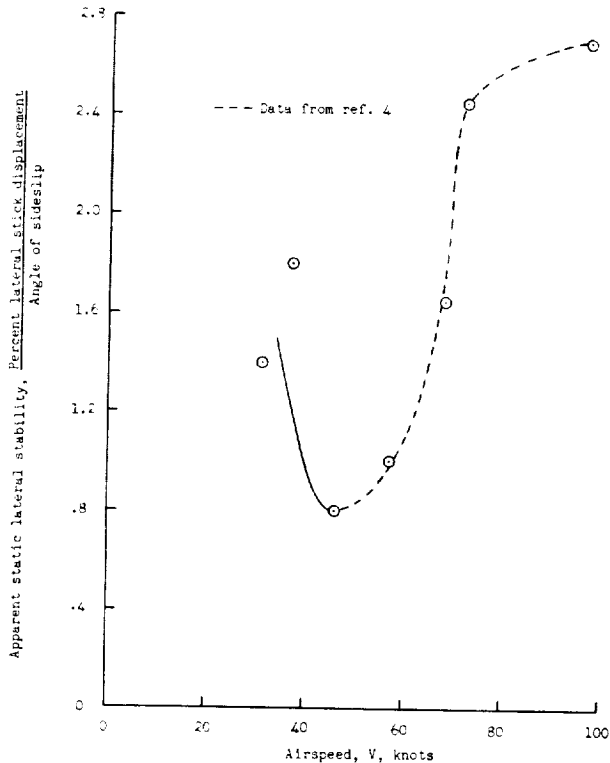


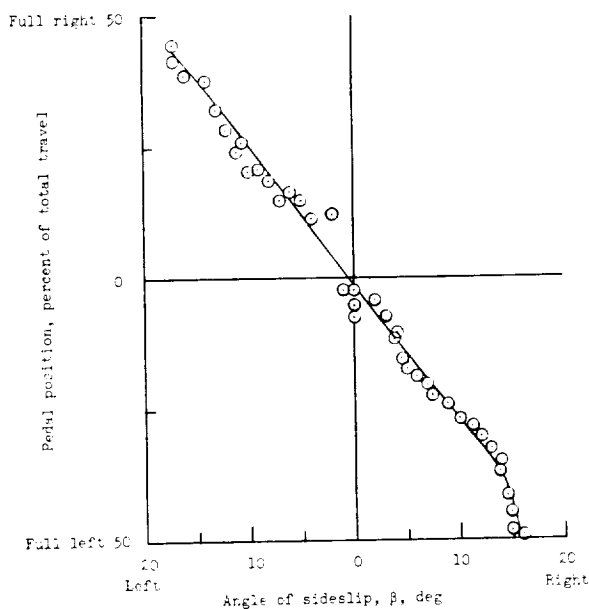
Figure 10.- Variation of apparent static lateral stability with airspeed, where airspeed is controlled by duct-angle setting.

data included in reference 4. Figure 11 presents these results for duct angles of 60° and 70° (at powers for trim level flight) in terms of pedal position and angle of sideslip. Satisfactory apparent directional stability is indicated. The apparent static-directional-stability data (including results from ref. 4) are presented as a function of airspeed in figure 12. An increase in the apparent static directional stability indicated by the data for the low-speed range (duct angles of 60° and 70°) is confirmed by pilot comment; however, it was considered too low for satisfactory flying qualities.

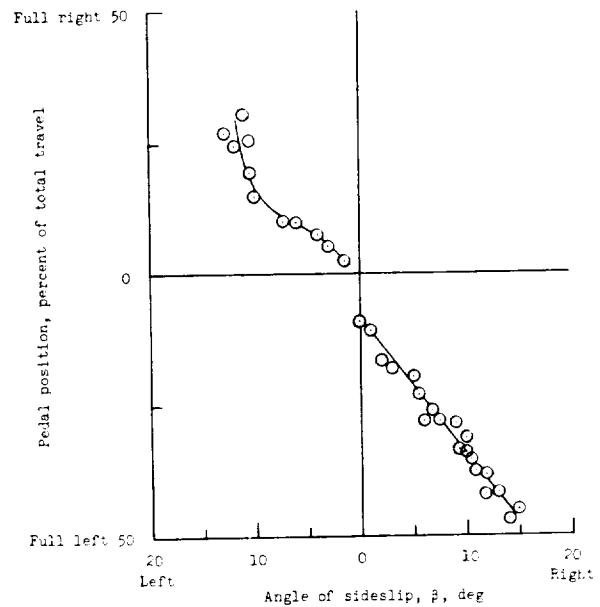
Roll control.- Measurements of the roll-control characteristics were made with the tilt-duct aircraft throughout the transition speed range (16 to 110 knots) and included duct angles between 80° and 0° . Results of this investigation are presented in figures 13 and 14. Figure 13 shows the roll-control power per inch of lateral stick displacement. Figure 14 presents the roll velocity per inch of lateral stick deflection. In order to meet the requirements of minimum roll angular displacement of reference 11 for visual

hovering flight in an aircraft of this size, the angular acceleration, or roll-control power (according to sample calculations), would have to be about six times as great. Controlability about the roll axis was very poor, particularly at the lower airspeeds, and was termed highly unsatisfactory at all airspeeds by pilot comment. The roll control available at cruise was about one-third of that needed to meet minimum requirements of reference 12. Thus, it is essential in future designs to provide larger rolling moments, possibly through differential collective pitch during hovering and transition speeds, and more effective ailerons during cruising flight.

Power-required characteristics.- Shaft horsepower required for level flight throughout the transition speed range is presented in figure 15. At a wing angle of attack of 6.5° data are presented for duct angles between 80° and 10° and for velocities from 15 to 95 knots. For duct angles between 60° and 30° , additional power-required data are presented for wing angles of attack of 10.5° and 2.5° . Curves for constant duct angles and constant angles of attack are shown in figure 15. It may be seen that at airspeeds below 80 knots, unstable speed-power variations would result if operational flight was along the curve of constant angle of attack and a varying duct angle. However, with the tilt-duct aircraft, at a given trim speed (and hence at a given duct angle), the curves for estimated



(a) $V = 37$ knots; $\alpha_w = 6.5^\circ$; $\delta_d = 60^\circ$.



(b) $V = 31$ knots; $\alpha_w = 6.5^\circ$; $\delta_d = 70^\circ$.

Figure 11.- Static directional stability for level-flight configuration at two low-speed conditions.

constant duct angles reflect the relationship between power required and speed. For the lower angle-of-attack range ($\alpha < 6.5^\circ$), a stable speed-power relationship - that is, increasing power for increasing speed - is indicated. This represents a highly desirable characteristic for a VTOL aircraft at constant duct angle, especially during low-speed instrument operation.

Power savings may be achieved throughout a major portion of the transition region by operating the aircraft at a high angle of attack; however, a large percentage of the potential advantage is lost at the higher duct angles due to flow separation over the wing. Stall delay devices would help alleviate this problem as mentioned in reference 4.

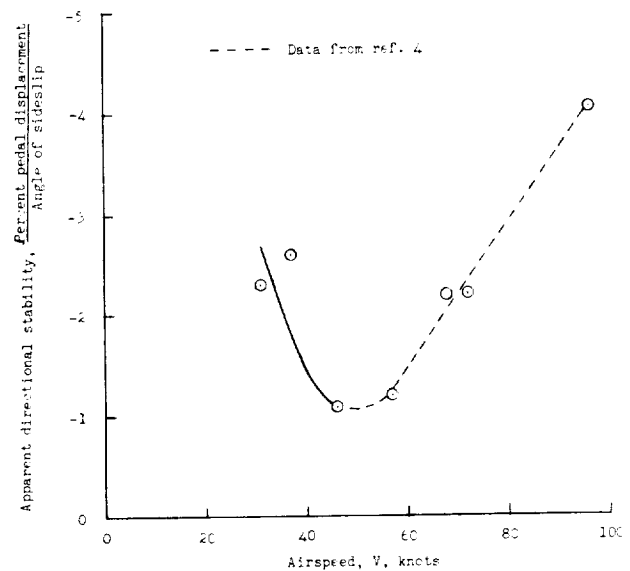


Figure 12.- Variation of apparent static directional stability with airspeed, where airspeed is controlled by duct-angle setting.

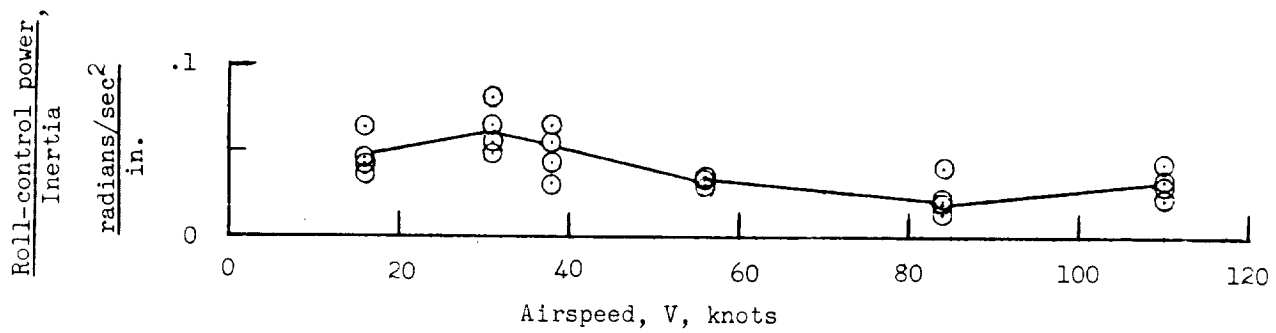


Figure 13.- Roll-control power per inch stick displacement plotted against airspeed.

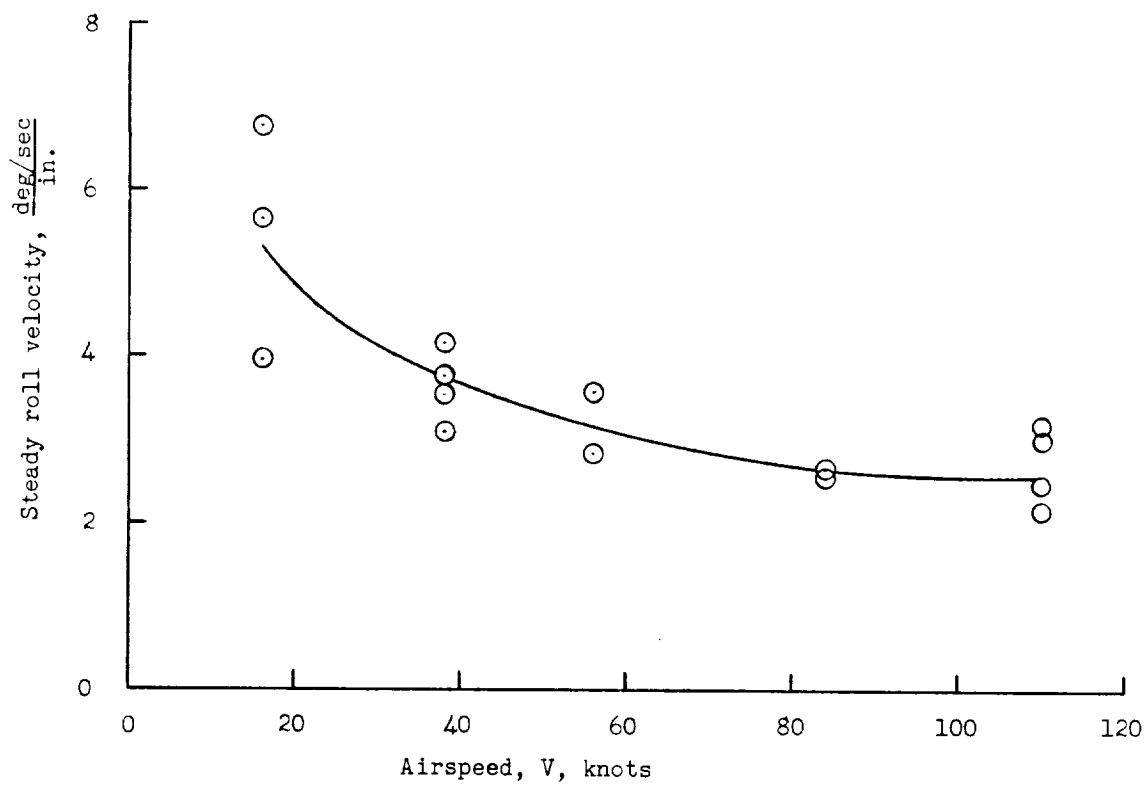


Figure 14.- Roll velocity per inch of lateral stick deflection plotted against airspeed.

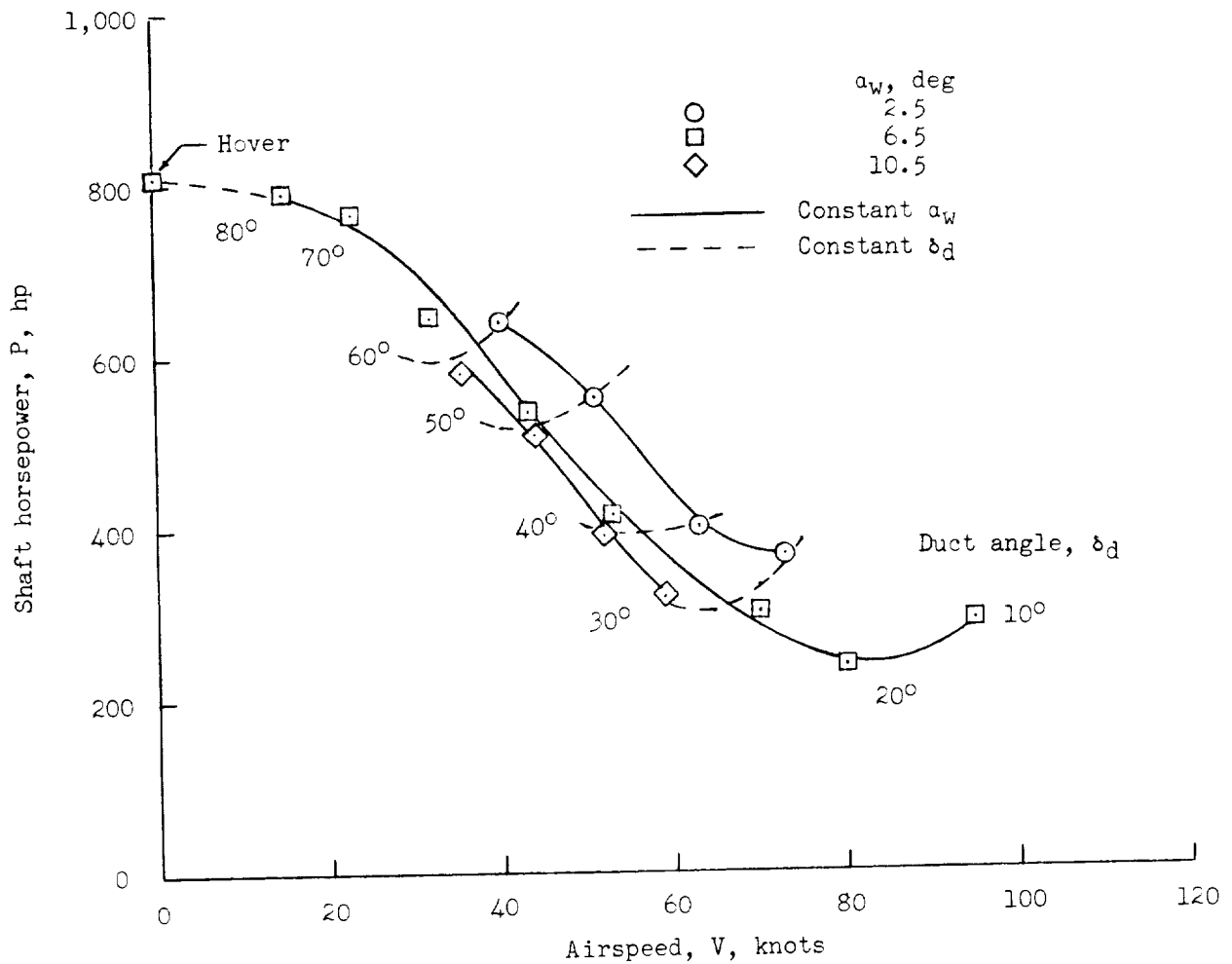


Figure 15.- Horsepower required for level flight throughout transition speed range.

CONCLUSIONS

A flight investigation which includes some of the operating problems and related aerodynamic characteristics of a fixed-wing, tilt-duct, vertical-take-off-and-landing configuration indicates the following conclusions:

1. The portion of the transition speed range most seriously affected by flow separation over the outer wing panels and ailerons was between 60 knots and 35 knots which includes duct angles between 35° and 60°. The effect of operating at a reduced power generally tended to restrict further any usable combinations of these parameters.

2. Of the three simulated ground-controlled steep-approach methods tried, the method in which the duct angle was increased upon intercepting the glide slope appeared to offer the most promise for operational use. The two other methods studied were judged unacceptable by the pilots.

3. Measurements of the roll control throughout the transition speed range indicated very low roll-control power and pilots' comments indicated that these control powers are inadequate.

4. Measurements of speed stability, directional stability, and effective dihedral indicated stability in most cases throughout the major portion of the transition speed range. At lower airspeeds the aircraft became more stable with airspeed as the duct angle was increased. Pilots termed the speed stability as satisfactory. In general, pilot comment indicated that the apparent directional stability and the apparent effective dihedral went from satisfactory at the high speeds of the transition speed range to unsatisfactory at the lower speeds of the transition speed range.

5. Measurements of the maneuver stability indicated less stable characteristics with decreasing airspeed. Maneuver stability was considered satisfactory only at airspeeds above about 60 knots.

6. Operation at a constant angle of attack and varying duct angles at airspeeds below 80 knots indicates that unstable speed-power changes would be experienced. However, when a constant duct angle is maintained and the speed or power is varied about a trim value, a stable speed-power relationship results. This is a highly desirable characteristic, especially during low-speed instrument approaches.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 14, 1963.

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